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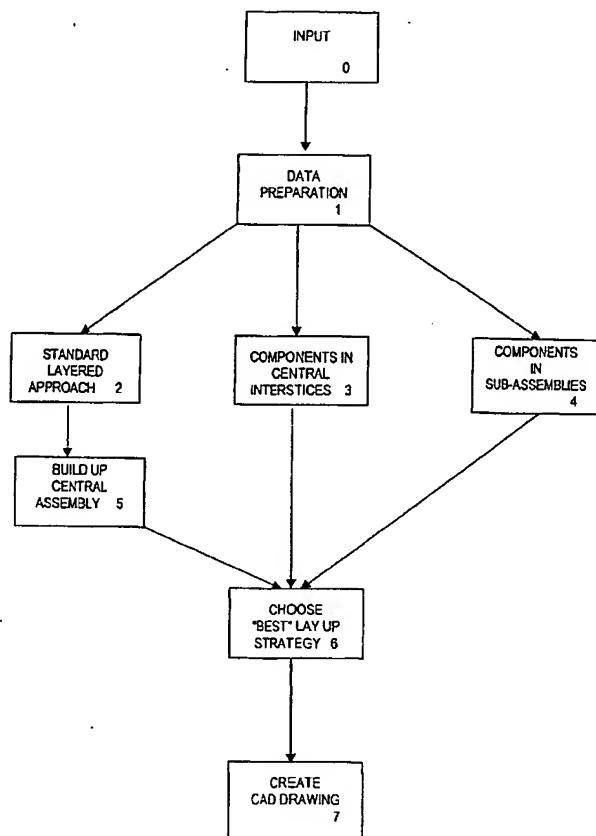
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(54) Title: DESIGN TOOLS FOR COMPOSITE ARTICLES



(57) Abstract: A computer-implemented method of determining and outputting automatically an arrangement of hoses and pipes to form an umbilical to be manufactured, the method comprising: receiving (0) from a user parameters of a desired article, said parameters defining a set of components having respective dimensions; performing automatically at least two processes (2, 3, 4) to generate at least two respective candidate arrangements of the components to form said composite article, such as placing hoses around a central assembly, or building up a component or the central assembly and evaluating said arrangements in terms of predetermined parameters to find a best candidate arrangement among them; and comparing (6) the best candidate arrangements generated by the different candidate processes to identify among them an overall optimal arrangement.



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DESIGN TOOLS FOR COMPOSITE ARTICLES

5 The invention relates to computer-implemented methods for the design of composite articles, where the number and type of components to be included in a composite article is specified by a user. The invention is particularly intended for combining a number of elongate articles, such as hoses, pipes and cables to form a single “umbilical” cable. Such cables are required in a wide variety of types, for example, for communication with diving equipment, and sub-sea vehicles and installations.

10

 Operation of vehicles and personnel to sub-sea environment is one example where a multi-purpose cable or “umbilical” is often required. Electrical cables, hydraulic and pneumatic control lines, fibre optic cables and the like may all be required in a single, flexible assembly. Depending on the application, the combinations of size and type of component required to make up such an assembly are practically infinite. Over many years, specialist design skills have evolved before the “laying up” of the component articles to be wound into an umbilical cable. The common design requirements include high flexibility, good durability, controlled buoyancy and minimum drag. To achieve the best dynamic performance and prevent stress build-up during bending, components are preferably laid up helically, in a planetary cabled construction. Lay angles may be selected to astute the construction and component design. As a general rule, the designer seeks to minimise the final overall diameter of the cable, by packing the components into a small diameter as possible. Load-bearing and armouring components may also be required, depending on the application.

25

 Larger supplies of such cables can evolve standard composite designs over a period of time, but there exists a constant demand for new designs, specific to a given customer or job. It is found that no single set of rules is adequate to obtain a near-optimal arrangement of the components in all cases, and the need for human design expertise therefore adds greatly to the cost and lead-time for the manufacture of such products. These field designers know that the optimal design for one set of components or global parameters may be far from optimal, when one component or operating parameter is changed even slightly.

30

It is an object of the invention to provide an automatic system for the design of umbilicals and similar products comprising an assembly of elongate articles.

5

The invention provides a computer-implemented method as defined in Claim 1 of the appended claims. By discussion with the designers within the applicant company, the inventor has identified a number of alternative candidate strategies which are consciously or subconsciously employed by the experienced human designers.

10

The method according to the invention includes trying a number of candidate processes, each evaluating a number of candidate designs, and yielding its own best design. The method then further includes selecting the "best of the best" designs from a variety of candidate processes, to identify what is hopefully a near-optimal design. It is envisaged that a human expert might still produce a better design to many cases, but a difference should be marginal, and the cost saving for routine design tasks will be great. Indeed, by automating the routine design jobs, the rare skills of the human expert designer will be more freely available to tackle more challenging design problems.

20 By automating only limited strategies for arranging the components, the computational task is kept within manageable proportions. By using a range of different limited strategies, however, the chances of finding a good arrangement for a given set of inputs are greatly improved.

25 Optimal features of the method, including particularly features of the preferred candidate processes, are defined in the dependent claims.

The invention further provides an apparatus for use in designing composite articles, the apparatus comprising a computer configured to implement a method according to the invention, as set forth above.

30

The invention further provides a computer-generated design record produced by the method set forth above.

The invention yet further provides a composite article comprising a plurality of elongate components, the arrangement of said components having been determined by use of the apparatus or method according to the invention, as set forth above.

5

The invention yet further provides a computer program product wherein computer-implementable program steps are recorded, so as to implement the method according to the invention as set forth above.

10 These and other aspects of the invention will be apparent to the skilled reader from a consideration of the exemplary embodiments, described below.

BRIEF DESCRIPTION OF THE DRAWINGS

15

Embodiments of the invention will now be described, by way of example only, by reference to the accompanying drawings, in which:

Fig. 1 is a flowchart depicting the overall design process according to one
20 embodiment of the invention;

Fig. 2 is a flowchart depicting a first candidate process within the process of Fig. 1 implementing a "standard layered" approach;

25 Fig. 3 shows a first example design resulting from the "standard layered" approach;

Fig. 4a and 4b form a single flowchart depicting a second candidate process implementing a "components in central interstices" approach;

30

Fig. 5 shows a second example design resulting from the "components in central interstices" approach;

Fig. 6 is a flowchart depicting a third candidate process implementing a "components in subassemblies" approach;

Fig.7 shows a third example design resulting from the "components in subassemblies" approach;

Fig.8. is a flowchart depicting an example of the "components in subassemblies" approach in operation;

Fig 9. is a flowchart depicting "build up central assembly" approach as a modification of the "standard layered" approach;

Fig. 10 shows a fourth example design resulting from the utilisation of the "build up central assembly" approach; and

15

DETAILED DESCRIPTION OF THE EMBODIMENTS

Introduction

20 An outline of the automated design apparatus and process is described below. This produces a CAD (computer-aided design) drawing of an Electro-hydraulic Umbilical from a given input. The input will specify the various component hoses and cables making up the composite product. In the manufacture, these must be laid up together in a compact arrangement, and twisted into a helical bundle for flexibility and robustness in
25 use.

The output will then be:

- An AutoCAD drawing in a predefined format
- 30 • If the designed product contains only standard components with no requirement for either armour or central member then the weight of the product will be calculated.
- Mechanical properties of the designed product

Development Tools

The application which carries out the method consists of two main parts - the GUI
5 (Graphical User Interface) which allows for the input of data and the 'Rules Base' which
develops a design from the inputs. Each has been developed using distinct tools. The
skilled person will from the following description be able to select appropriate tools for
creating his own implementation of the system. The GUI, in the present embodiment was
developed under Visual Basic 6 with the 'Rules Base' being developed in Intent!
10 specialised design automation tool, which provides full integration with AutoCAD.
Intent! is available from Heide Corporation, 5 West Mill Street, Medfield, MA 02052,
USA (www.heidecorp.com).

15 Elicitation and Development of the Design Rules

From talking with and observing designers of Electro-Hydraulic Umbilicals the
inventor determined that, for the application to meet the system requirements, focus
should be on the geometric rules which the designers employ when developing a design.
20

Design Strategies

From analysis of the design process within the applicant company, it became apparent
25 that there are four different strategies which the designers employ to reach an optimal
solution. Other strategies may be favoured by other designers, and the invention is not
limited to these specific examples. The four strategies are are:

1. Standard Layered Approach – a strategy which develops a design by placing every
30 component in a concentric layer.
2. Placing components in the interstices. – Utilising the interstices (the space between
components) by placing components of appropriate size in the interstitial space, it is
possible to reduce the OD of the assembly.

3. Creating sub-assemblies of components. – By grouping several small components together, a sub-assembly which is of similar size to larger components to go in the design can be created This can lead to a smaller product.
4. Central Assembly Build-Up. – By increasing the size of the central assembly with layers of filling material, it is possible to increase the number of components which can be accommodated in a layer, possibly resulting in a reduced overall OD.

By developing the system to look at these four design strategies an application has been produced that can, for the Electro – hydraulic domain, match exactly the design produced by an experienced human designer in between 60 and 70% of cases and will give a reasonable response in the remainder of cases. The automated design process can be provided by field sales personnel, or as an on-line application for routine design problems.

15 Data Flow and Decision Making

As can be seen from the flowchart of Fig 1 the process of creating a design from the inputs has been broken into seven clearly defined modules:

0. Input Specification
- 20 1. Data Preparation.
2. Try “Standard Layered” Approach.
3. Try “Build up Central Assembly” approach
4. Try “Components in Central Interstices” approach.
5. Try “Components in Sub-Assemblies” approach.
- 25 6. Choose “Best” Lay Up Strategy.
7. Create CAD drawing.

Hardware Implementation

30 Each of the seven modules could, in principle, be implemented in a separate apparatus, but there is no reason why they should not be implemented sequentially by programming on a general purpose computer.

Fig 11 illustrates a typical hardware implementation, in which a personal computer workstation PC provides the following hardware components:

DIS: video display for a user;

KBD: keyboard, mouse etc for user input;

5 STO: mass storage for data being processed, and also storing programs, databases
 of prior designs and standard component types, sets of design rules;

PRN: hard copy printer; and

CDW: removable storage writer.

10 The hardware within the PC workstation is conventional, and of course developing
constantly with advances in computer technology. Software within the PC implements
three main parts of the system, namely a graphical user interface GUI for input and output
to the user on an interactive basis, a design process DES which is the particular subject of
the present application, and a CAD system based on commercially available software, for
15 presenting the output of the design process in a form suitable for manufacture.

There is no need for all of the components to be executed on the same PC, or at
the same time. In embodiments which are envisaged, the user may be remote from the
design process. In particular, the user interface GUI could be implemented over a network
such as Internet. Automatic security and payment procedures might be implemented, or
20 use of the system limited to authorised field personnel. Similarly, the design output on
paper or disc could be at a remote factory location, perhaps in another country. In yet
other embodiments, the CAD output may further be used to control directly a computer-
aided manufacturing production apparatus.

25 The seven process modules mentioned above will now be described in detail:

0. Input Specification

Firstly certain parameters have to be entered via the GUI. In the preferred example these
30 parameters are:

- Number of hoses – either standard or non standard

- If the hoses are non standard then both the Overall Diameter (OD) and Inner Diameter of the hose need to be entered. For standard hoses these parameters are automatically retrieved from a database.
 - Number of electrical pairs – limited to one type per design in this embodiment and again either standard or non-standard.
 - The OD of the electrical pair – if standard then these are retrieved from a database, otherwise they must be entered manually
 - Number of electrical quads – limited to one type per design in this embodiment and again either standard or non-standard.
 - The OD of the electrical quad – if standard then these are retrieved from a database, otherwise they must be entered manually
 - Whether or not the completed design requires a simple two layer armour package - Yes or No
 - Whether a central member is required – Yes or No. If yes, then a further question must be answered - what is the breaking strength of the member?
- Additionally, global parameters may be specified, such as a "fill factor" determining the tightness of packing, or a total neutral buoyancy in water.

1. Data Preparation

The process defined as Data Preparation takes the given input of number, type and size of component, and conditions it such that the information is in a form suitable for further processing.

Specifically two lists are created, one containing the different OD's to go into the design and a corresponding list outlining the number of components at each size that are to go into the design.

For example: if we had 4 hoses of OD 30, 3 of OD 25, 2 of OD 12.3, 6 pairs (bundle of 2 hoses) at OD 25 and 2 quads (bundle of 4 hoses) at OD 12.3 then the lists created by the process would be {30;25;12.3} and {4;9;4}.

These two lists give enough information to begin the process of creating a design. At this stage it is simply a matter of maximising the use of space (volume), the type of component is not, yet, an issue.

The data created here is then passed on to the modules which look at the different design strategies, the modules will then process the data according to the rules specific to that strategy.

5 2. Standard Layered Approach

This approach basically involves accommodating all of the components in layers radiating from a central assembly. This approach is explained in detail below and illustrated in the flowchart of Fig 2.

10 Essentially we are interested in only the size of the components to go in the assembly and the number at each size, therefore the algorithms herein receive and deal with two lists called: ComponentODlist and NumberOfComponents (steps 20a and 20b). These lists mentioned above, refer to the OD's of the components to go in the assembly and the number of each.

15 The goal here is to look at all of the different ways of combining the given components and choose the optimum one i.e. the one that gives the smallest OD. Other parameters such as weight are also an issue, of course. Before it can be decided which lay-up gives the best solution (in terms of OD), almost all of the combinations of the component will be created, then how to put them together according to the rules will be
20 calculated and finally the OD will be calculated.

 In the strategy outlined by the designers within the applicant company, they looked at creating a central assembly which consisted of between one and five components and then created subsequent layers around this. Therefore to emulate this process, at step 21 of this module, the ODs of central assemblies consisting of 1, 2, 3, 4
25 and 5 components of every OD given in ComponentODlist is calculated (in an attribute called CentralDiameterList).

 Step 22 creates all of the possible ways of ordering the components, it will follow that this will give us most of the ways of combining the components into layers.

 The reason the permutations of the entire list are not calculated is down to
30 performance of the system. It would take a considerable amount of time to permute even 20 combinations ($20! = 2.43 \times 10^{18}$). Overcoming this problem is a simple matter of taking the permutations of the ComponentODlist. This vastly increases the speed of the process. Therefore, if there are three differently sized components to go in the design there would be six (3!) different ways of putting them together.

Then, at step 23, by taking the permutations of Component OD and using the list NumberOfComponents it is possible to create six lists which represent all of the components to go into the design, with the separate component OD's in blocks, the size of each block being dictated by the list NumberOfComponents. To illustrate this point see
 5 the example below.

Assuming the following inputs: 3 Hoses @ 30mm OD
 8 Hoses @ 12mm OD
 6 Pairs @ 15mm OD

10

The ComponentODlist would be: {30; 12; 15} (step20b)
 and the NumberOfComponents would be: {3; 8; 6} (step 20a)

As stated above, the attribute CentralDiameterList is a list which contains the
 15 OD's of central assemblies comprising of between 1 and 5 components of each size. Using a standard formula it is therefore possible to create 3 lists (one for each component OD) each with 5 elements (1-5 central components).

This means, in the example above, the three lists would be, assuming a fill factor of 98% and a lay-up angle of 13°:

20

{32.34; 60; 65.32; 73.7; 82.86} – corresponds to 30mm component (step 21)
 {16.17; 30; 32.66; 36.85; 41.43}-- corresponds to 15mm component
 {12.94; 24; 26.13; 29.48; 33.14}-- corresponds to 12mm component

25 The next stage would be to create the permutations of ComponentODlist:

 {30; 12; 15}
 {30; 15; 12}
 {15; 30; 12}
 {15; 12; 30}
 30 {12; 30; 15}
 {12; 15; 30} (step22)

Using these lists and the information given in the list NumberOfComponents, the six ways of grouping the components together in blocks can be created:

- 5 {30; 30; 30; 12; 12; 12; 12; 12; 12; 12; 12; 15; 15; 15; 15; 15; 15}
 {30; 30; 30; 15; 15; 15; 15; 15; 15; 12; 12; 12; 12; 12; 12; 12; 12}
 {15; 15; 15; 15; 15; 15; 30; 30; 30; 12; 12; 12; 12; 12; 12; 12; 12}
 {15; 15; 15; 15; 15; 15; 12; 12; 12; 12; 12; 12; 12; 12; 30; 30; 30}
 {12; 12; 12; 12; 12; 12; 12; 12; 30; 30; 30; 15; 15; 15; 15; 15; 15}
 {12; 12; 12; 12; 12; 12; 12; 12; 15; 15; 15; 15; 15; 15; 30; 30; 30} (step 23)

- 10 There is now enough information to begin the process of assembling the components into a lay-up.

At step 24, for each the six lists above (grouping into blocks), the most efficient way of assembling the components into a layered arrangement is calculated. In the application this task falls to two functions: CalcLayUp and ComponentsPermitted.

- 15 Basically this entails trying to place the components of each list into concentric layers, with the components towards the left hand side of the list in the centre of the assembly and the components towards the right hand side of the list in the outer layers.

For example, taking the first grouped list:

- 20 {30; 30; 30; 12; 12; 12; 12; 12; 12; 12; 12; 15; 15; 15; 15; 15; 15} (list I)

The size of central assemblies consisting of 1, 2, 3, 4 and 5 30mm components is known:

- 25 {32.34; 60; 65.32; 73.7; 82.86} (list II)

- 30 The process is begun by hypothesising on using a central assembly consisting of one component of size 32.34mm (position 1 in list II). This would mean placing the first component of list I into the central assembly. Then position two of list I is looked at in order to see the size of the components to be placed in a layer around this central assembly. Using a standard formula, the number of components of size 30 that can fit around an assembly of OD 32.34mm is calculated, the answer being 6. This takes us to position 7 of list I. Of course there are not six remaining components of size 30mm and

therefore to carry out this instruction 4 components of size 12mm must be used. This is permitted as 12 is smaller than 30 which means that these components can be built up to equal 30mm.

Therefore the first 7 components of list I fit as thus:-1 component of 30mm is placed in the central assembly and 2 more placed in the first layer along with the 4 components of 12mm these having been built up to 30mm.

The remaining components are placed into subsequent layers. The next component to look at therefore is position 8 in list I, which is 12mm. The number of components of OD 12mm that can be fitted around a central assembly of size 92.34 ($32.34+30+30$) is calculated to be 26. This, of course, would allow all of the remaining components into this second layer to be accommodated. However within the sub-list from position 8 till the end, there are components of OD 15. Now as 15 is greater than 12 this result is discarded (15mm cannot be built up to 12mm!). Instead the number of components of the larger size (15mm) that can fit around the central assembly of 92.34 is calculated. This gives an answer of 21, and therefore 21 components of OD 15mm can fit around the first layer. This figure gives enough leeway to accommodate all of the 15mm components and the remaining 4 components of OD 12mm, built up to the larger diameter.

Therefore the components fit into an assembly in the order given in list I by having 1 component of OD 30mm in the centre with a first layer comprising of 6 components and a second layer with 21 components. This would have an overall OD of $32.34 + 2*30 + 2*15 = 122.34\text{mm}$.

This process is carried out for each of the five different configurations of the central assembly. Once all these possible combinations are calculated then, at step 25, the optimum combination can be chosen. This is the design with firstly, the smallest OD and secondly, the least number of fillers.

Figure 3 shows the CAD drawing produced using this approach for an input of {19.6;18.5;13.2} (ComponentODlist) and {2;5;2} (NumberOfComponents).

There is a total of 6 (3!) lists for both inputs, these being: {19.6;18.5;13.2}; {19.6;13.2;18.5}; {18.5;19.6;13.2}; {18.5;13.2;19.6}; {13.2;19.6;18.5}; and {13.2;18.5;19.6}. The corresponding numbers lists would then be {2;5;2}; {2;2;5}; {5;2;2}; {5;2;2}; {2;2;5}; {2;5;2}. From these lists, six lists representing all of the different ways of ordering these components (with the common OD's grouped together) are created, so the first list would be:

{19.6;19.6; 18.5;18.5;18.5;18.5;18.5;13.2;13.2 }.

5 The full assembly is then calculated as explained above. Points to note are that the system chose to place the two smaller electrical pairs in the centre with the larger components in the first layer. To keep the design symmetrical the component at 18.5mm was built up to 19.6mm, to match the larger component in the first layer

3. Components in Central Interstices

10

This approach involves placing components of suitable size in one or more interstices of the central assembly. This effectively removes the need to place these components in the outer layers of the assembly. This can result in a design with a reduced OD. A flowchart of this approach is shown in Figure 4(a+b). The best way to illustrate this approach is by an example.

15

For this example a design containing 2 hoses with an OD of 20.5mm, 13 hoses with an OD of 12.5mm and 2 twisted pairs with an OD of 12.5mm is to be produced, these ODs are therefore inputted at step 310.

20 The one difference in this strategy is that only the central assembly made up of the largest sized component to go into the design is considered, which, in this case, would mean the 20.5mm component would be chosen at step 311. Then, at step 312, the ODs of central assemblies made up of 1-5 components of (in this case) OD 20.5mm are calculated: In this case these would be:

25 {22.1;41;44.3;49.8;55.93}

At step 313, the size of any interstices in the 4 central assemblies which has them is calculated (obviously there are no central interstices when the central assembly consists of only one component). Therefore, the central assemblies made up of between 2 and 5 components will contain interstitials.

30

A list of the OD of the outer interstices of a central assembly is constructed. The number of components in the central assembly is told by the position of each OD, so position 3 has the OD of an interstice when there are 3 components of OD 20.5mm in the central assembly (9.3mm).

{0;13.1;9.3;7.9;7.3}

At step 314, using the above data, these OD's are compared with the OD's of the components and, at step 315, the question of whether any of the components will fit into the interstices is considered. If not then this strategy is discontinued and others are tried.

At step 316 each central assembly configuration is examined and the configurations that can accommodate components in their interstices is identified. It is clear, for instance, that a central assembly composed of 2 components with an OD of 20.5mm could accommodate two components (one in each interstice) of OD 12.5mm (12.5 being smaller than 13.1). This is the only possible use of the interstices in this example, as the rest are too small to accommodate any components, Therefore, this configuration should be concentrated on.

In combination with the list NumberOfComponents which has been modified at step 317 to reflect that components have been placed in the interstices, at step 318, the permutations of the blocks of components and the OD of the central assembly containing between 1 and 5 components with the greatest OD (20.5) are calculated.

In this example, the permutations of the blocks of components are limited to only 1. There are two differently sized components, giving 2 possible combinations of the blocks of components (2!), however only the combination where the central assembly is made up of the largest component (20.5mm) is to be considered.

Therefore the input block is:

{20.5;20.5;12.5;12.5;12.5;12.5;12.5;12.5;12.5;12.5;
12.5;12.5;12.5;12.5; 12.5;12.5}

From here, at step 319, two alternative solutions can be examined. The first of these by placing a single component of OD 12.5mm in one of the interstices and the second by placing two components in both the interstices.

Therefore, the number of components of 12.5mm that can fit around a central assembly of OD 41mm (2 components of 20.5mm) is calculated (13). "This is the best solution, and would therefore be the one chosen at step 320, as two components of OD

12.5mm can be placed in the interstices of the central assembly, leaving the remaining 13 components to go in the first layer.

Figure 5 shows an example of this approach for an input as follows:

1 Hose @ 18.5mm; 15 Hose @ 12.5mm; 5 Hose @ 15.5mm;
 5 Hose @ 14.7mm; 1 Hose @ 20.5mm; 6 Pairs @ 14.7mm.

In this example the system has chosen to place the two largest components in the central assembly, building up the 18.5mm component to 20.5mm. Among the calculations done by the system is that of the size of the central interstitial spaces in the central assembly. Here it has calculated that the interstitial OD is large enough to accommodate a component of OD 12.5mm. In this case it has decided that the optimum lay-up is to place two of the 12.5mm components in the central interstitials, allowing the remaining components at 12.5mm to be placed into the first layer, and the remaining components being accommodated in the second layer.

4. Components In Sub-Assemblies

As with the interstitial approach above, 'Components In Sub-Assemblies' looks to alter the original lists in 'Data Preparation' in line with the rules for the creation of sub assemblies. A flowchart for this approach is shown in Figure 6.

This approach attempts grouping components together such that the group OD is approximately equal to that of other, larger, components in the input. For example, consider the following components: {30;15.5;12.5} and the corresponding numbers {5;1;27}. It is known that by combining 3 components at 12.5 will result in a grouping with an OD around 30. It is also possible to take a component of OD 15.5 and group this with a 12.5 component which has been built up to 15.5. This again would result in a grouping whose OD was around 30.

This, therefore, has introduced many more design possibilities: the original NumberOfComponents list of {5;1;27} could be transformed into {6;0;26} by using a group containing 1 at 15 and 1 at 12.5, or, by taking 2 groupings of 3 at 12.5 and 1 grouping of 2 at 15 (with one 12.5 built up) we would transform the list into {8;0;17}. Therefore it is easy to see that by creating the sub assemblies the number of design possibilities have been greatly increased. The manner in which subassemblies are formed is described in detail below.

The process shown in Figure 6 comprises a routine called Subassemblysoo, which essentially takes the information supplied in the file 'input' (step 400) and merges the

hose, pair and quad data to return single ordered lists containing the combined ODs of the different component types – ‘SizeList2’ and also the corresponding number of each sized component – ‘CompnumSorted’. With the input information in this form, it is possible to calculate the possible subassemblies which may be constructed from the components
5 available.

The simplest case is where the subassemblies are composed of between 2-5 components only, the geometry of which being identical to the current central assembly construction of the complete lay-up. The case of one component forming the subassembly is trivial and is equivalent to the case in which a component is built up to a
10 larger component and is therefore dealt with elsewhere.

The algorithm begins, at step 401, by establishing the ODs of the subassemblies which may be considered. This is achieved by taking the ODs of the components given and considering all of these with the exception of the smallest.

Taking the ODs returned at the above step, the component sizes which are
15 possible contenders to fill each of these subassembly ODs must be found. Given the subassembly OD, the components of which it may be comprised are found simply by listing all component ODs which are smaller than it. This is given in the file ‘CenterSize’. With all the possible component ODs which can fit each subassembly OD known, the OD for assemblies of 2-5 of each component given in ‘CenterSize’ is
20 calculated. This is done at step 402.

At step 403, the attribute ‘CAODallowed’ accepts the subassembly constructions which have dimensions within certain limits while discarding the rest. These limits are such that only subassemblies that are approximately the same size as each of the component ODs returned at step 401 being considered, i.e. subassemblies that have ODs
25 no greater than the component OD+1mm and no smaller than the 95% of the component OD are accepted.

Now, at step 404, all the possible subassembly constructions which are feasible are established and every permutation of these are calculated. Taking into account the number of components at each OD, it must be ascertained whether components are
30 actually available to construct the subassemblies given in ‘CAODallowed’. If there are insufficient components of the desired OD, then smaller components (built up) in the list ‘SizeList2’ can be considered. The attribute ‘CACompositionList’ calculates all this and returns the component ODs which will actually be used, together with the corresponding

number required. From this, the components remaining once each of the possible subassemblies have been constructed is obtained. This is done by taking the contents of the subassembly and deducting these components from the original list of components available and increasing the number of components of the size which is created in the construction of the subassembly. A list of each component type and the updated
5 corresponding number of the component is returned. These lists are then used to calculate every possible combination of each of the subassemblies by systematically subjecting the original 'CompnumSorted' (see above) to each subassembly change-in-number list repeatedly until no more subassemblies may be 'applied'. The components remaining are
10 returned together with a tally of the number of each subassembly used to arrive at this number of components remaining.

Before the different combinations of subassemblies in a given lay-up can be entertained, a representation of each subassembly must be given. To this end the change-in-number representation as described above is adopted. This is calculated in
15 'PermutationsOfSAs1' by comparing the original list of components available with that of the components remaining for a particular subassembly construction. The 'permutationsofSAs2' - 'permutationsofSAs6' attributes generate the different combinations of subassemblies which may comprise a lay-up. This is achieved using the function 'SubassemblyPerms' which takes each subassembly's change-in-number list
20 (from 'PermutationsOfSAs1') in turn, and applies it to the number of components available. This returns the updated number of components available (to which the next subassembly change-in-number list is applied) as well as maintaining a tally of the subassemblies which have been used. Any duplicate compositions which arise are discarded.

25 At step 405, for each of the lay ups returned above, lists are created of the different component ODs that make up each assembly. These lists should include the exact ODs of the subassemblies included in the lay-up.

At step 406, for each list, the largest component of the list generated at step 405 that is to go into the assembly is selected. Then, as before, the size of a central assembly
30 consisting of between 1 and 5 of the largest assembly is calculated (step 407) and permutations of the order in which the remaining components (in blocks of equal OD) can be arranged is generated (step 408).

Finally, at step 409, 'Subassemblysoo' calls the file 'OptimumLayup' which, as the name suggests, computes the optimum overall lay-up. This file takes all the possible configurations which include the subassembly information returned by the file so far and returns the optimal configuration dictated by the requirements for the smallest OD
5 followed by the configuration which employs the least number of fillers.

There is a further step. In order to ultimately produce the drawing of this optimal configuration, the component type (hose, pair, quad or filler) of every component featuring in the lay-up must be identified and listed in the order in which they appear in the lay-up. This is achieved in four stages. In the first stage, 'SubComp_List1', taking
10 into account how many of each subassembly contributes to the optimum lay-up (given in the tally), the total change-in-number is calculated by firstly taking each subassembly change-in-number list in turn, and multiplying by the number of this subassembly required in the optimum lay up, taking the corresponding number from the tally. These are then added together to return the total number of each component OD required (to
15 form a subassembly) or acquired (in the form of a subassembly). In the second stage, 'SubComp_List2', runs through the hose, pair and quad information as supplied in the 'input' file and, for the number of components required for each OD, keeps a record of the number of each component type to be used where it is both required and available. e.g. if 5 components of 12.5mm are required in total for the construction of all the
20 subassemblies in the optimal lay-up, and there are 3 hoses available at 12.5, 1 quad at 12.5mm and no more components at this size, 'SubComp_List2' would return {3;0;1;1} indicating that 3 hoses, 0 pairs, 1 quad and 1 filler would be used. 'SubComp_List3' takes the output of 'subcomp_list2' and simply returns the actual component types so {3;0;1;1} would be given as {hose2;hose2;hose2;quad;filler}. Therefore, given that the
25 optimal lay-up contains subassemblies which in total require 5 components at 12.5mm, it is now known that 3 of these will be a hose, one a quad and the other a filler. The routine of 'SubComp_List' runs through each subassembly and allocates the appropriate component names to each subassembly. Thus, if the lay-up consisted of the following two subassemblies, {15.5;12.5} and four at 12.5 {12.5;12.5;12.5;12.5} and given that we
30 had one hose at 15.5mm, 'SubComp_List' would return {hose2;hose2} and {hose2;hose2;quad;filler} respectively.

The position of the subassemblies in the final lay-up must also be calculated. This is done by taking the sizes of each of the subassemblies to be used in the lay-up, and then

by finding the first occurrence of each size in the sorted list of ODs of the complete lay-up. The remainder of the 'OptimumLayup' file simply reorganises previously calculated data to return the output lists which are a prerequisite for the file 'automate'.

With the best lay-up known, all that remains is for a routine to identify, as either a
5 hose, pair, quad or filler, each component in each of the subassemblies.

An example of an output using subassemblies is shown in Figure 7, which depicts a CAD drawing for an input of: 5 Hose @ 30mm; 1 Hose @ 15.5mm; 27 Hose @ 12.5mm. Here the system has chosen to combine a number of the smaller components into a sub assembly to match the OD of the largest component. This then allows all of the
10 smallest components to be accommodated in the second layer.

A further flowchart highlighting this example is depicted in Figure 8. The steps match the steps of the flowchart of figure 6.

For this example, the input at step 400 would be (30;15;12.5) and (5;1;27), and, therefore, at step 401 the component ODs to be matched is (30;15.5) (all ODs bar the
15 smallest).

At step 402, assuming the subassembly OD to be constructed is 30mm, then the corresponding list in 'CenterSize' of components which can fit into this OD is {15.5;12.5}. Consequently, we can build subassemblies approximating these sizes. Therefore, for each of these components, the OD for 2-5 of each component in
20 'CenterSize' would give {{31.0;33.5;37.7;42.3};{25.0;27.0;30.4;34.1}}. At step 403, (taking the examples of the 30mm component), only subassemblies approximately matching the 30mm OD are considered. The attribute 'CAODallowed' does this, firstly, by running through both the lists above, discarding any results where the OD is greater than (30+1)mm, returning a result: {{31.0};{25.0;27.0;30.4}}, and secondly, by
25 discarding results that are smaller than 95% of the subassembly OD to be constructed, which leaves just {{31.0};{30.4}}.

At step 404, using the example of the 30mm component formed from a 15.5mm and a 12.5mm component (the latter built up due to there being no remaining 15.5mm components), then we require the following so-called 'change-in-number' list {1;-1;-1}
30 which indicates that in order to form this particular subassembly, the 30mm component increases by +1, the 15.5mm component decreases by -1 and the 12.5mm component also decreases by -1. Combining this with the list NumberOfComponents results in a modified list of ((6;0;26);(1;0)), the second bracket indicating that the first bracket includes one

subassembly of the first type (31mm). Similarly, the example using 4 12.5mm components returns (1;0;-4) and ((6;1;23);(0;1)).

Step 405 creates modified component OD lists which include the exact OD of any subassemblies that are to go into a particular lay up, in this case (31;30;15.5;12.5) [note 15.5 is still included though there are no components of this size remaining. This is resolved by having 0 at the corresponding point of the modified number of components list]. and (30.4;30;15.5;12.5).

At step 406 the largest component is selected for each lay-up (31 and 30.4) and , at step 407, using known functions the size of central assemblies consisting of between 1 and 5 of these components are calculated as (32.8;60.8;65.8;74.0;83.0) for the 30.4 subassembly example.

Steps 408 and 409 then generate the permutations and choose optimum configuration as with the other examples (again just for the 30.4 subassembly example:

```

15      {{30.41;30;15.5;12.5},{30.41;30;12.5;15.5},{30.41;15.5;30;12.5};
      {30.41;15.5;12.5;30},{30.41;12.5;30;15.5},{30.41;12.5;15.5;30}}
Step 408

```

```

20      {30.41;30;30;30;30;30;15.5;12.5; 12.5; 12.5; 12.5; 12.5;
        12.5; 12.5; 12.5; 12.5; 12.5; 12.5; 12.5; 12.5; 12.5; 12.5;
        12.5; 12.5; 12.5; 12.5; 12.5; 12.5}          Step 409

```

5. Build Up Central Assembly

25 This design strategy is similar to the standard layered approach in that it aims to place all the components in layers around a central assembly. The major difference is that the system looks at building up the OD of the central assembly in order to accommodate the required components in the smallest possible OD. A flowchart depicting this approach can be found in Fig 9.

30 The technique employed by the system is to take the central ODs of 1- 5 central components, as before, and increasing each of them incrementally by 3% steps up to a maximum of 69%. We can then use the function described above to calculate the best lay-up for each of the revised central OD's, choose the optimum one ready for comparison with the other strategies.

35 This could allow the design to accommodate more components into a layer than
would have been possible previously, sometimes even a small increase of the diameter

can make a dramatic difference. To highlight this approach an example is demonstrated below.

For this example 1 hose with an OD of 30mm and 14 hoses with OD of 15mm are considered and inputted at step 500.

5 The starting point is the same as with all other strategies, that is by creating the permutations of the blocks of components. In this case there are two different input OD's so there will be 2 permutations ($2!$), these are:

	{30;15;15;15;15;15;15;15;15;15;15;15;15;15}	
10	and	Step 501
	{15;15;15;15;15;15;15;15;15;15;15;15;15;30}	

And at step 502, using the list NumberOfComponents entered at 500 lists demonstrating the ways in which the blocks of component ODs can be arranged

15 Next, for each of the ODs, the OD of a central assembly composed of between 1 and 5 components is calculated.

For the 15mm OD component this would be:

20 $\{16.2;30;32.4;36.4;40.9\}$

and for the 30mm component: Step 503

25 {32.3;60;64.8;72.9;81.8}

There is now enough information to begin the process of creating the various assemblies, from which optimum one can be chosen.

So far, this has been no different from the procedure outlined in Standard Layered
30 Approach. The only difference comes in the size of the central assembly from which the
lay-up was calculated. This is achieved by increasing the OD's of the above lists in 3%
increments up to 69%.

For example the central assembly OD list of the 30mm hose above will increase from:

{32.3;60;64.8;72.9;81.8}

5 to

{33.3;61.8;66.7;75.1;84.2} (3% increase)

and

Step 504

{34.2;63.6;68.7;77.3;86.7} (6% increase)

up to:

10 {54.5;101.4;109.5;123.2;138.2} (69% increase)

The same is done for the central assembly list corresponding to the 15mm OD hose.

Now, at step 505, the components are accommodated around each of these revised
15 central assemblies, as well as the standard approach assembly from step 502.

The central assembly list with a 3% increase is such that 15mm components are placed around the 30 mm component built up to 33.3 mm. This allows 9 components to be accommodated in the first layer, and would require a second layer to place all 14 components of 15mm. This gives an assembly of OD of 92.3mm (32.3+30+30).

20 Moving on to the case where the central assembly is built up by 69% (from 30mm to 54.5mm), It can be calculated that a total of 14 components of OD 15mm can fit around a central assembly of 54.5mm. This, therefore, means that all of the 15mm hoses can be accommodated in a single layer around such a built up central assembly. The OD of the assembly is 84.5mm (54.5+30) which is indeed the optimum configuration returned
25 at step 506.

Fig 10 shows an example of a CAD drawing generated using this approach.

6. Choose "Best" Lay Up

This module takes the information from the four modules above and chooses
30 which configuration will give the best lay-up with respect to OD. If two or more configurations have the same OD then it will consider how many fillers are in the assembly and choose the one with the least number of fillers. Of course in a practical embodiment, any number of parameters, including weight, for example, can be

considered in determining what is the "best" lay-up among a given set of candidate designs.

7. Create CAD Drawing

5 The creation of the CAD record and drawing is done via the link between Intent! and AutoCAD. The information passed to this module only outlines the configuration of the components to go into the design i.e. the number and size of the components to go in the central assembly, the number and size, if any, of components to be placed in the central interstices, the number, if any, of sub assemblies and what they contain and finally
10 which component ODs are to go in the layers.

 This module, before creating the drawing, must match up the component ODs and in the case of hose's nominal bores, to specific component types i.e. hose, pair or quad. Once this is done it is 'simply' a case of creating these components and placing them in the correct position and order.

15

Conclusion.

 The skilled reader will appreciate that numerous variations are possible within the principles of the apparatus described above. More or fewer strategies may be tried, and
20 variations on each can be provided within the rule sets. Accordingly it will be understood that the embodiments illustrated herein are presented as examples to aid understanding, and are not intended to be limiting on the scope of the invention claimed.

CLAIMS

1. A computer-implemented method of determining automatically an arrangement
5 of a set of elongate components to form a composite elongate article, the method comprising:
- receiving from a user parameters of a desired article, said parameters defining a set of components having respective dimensions;
- performing automatically at least two candidate processes to generate at least two
10 respective candidate arrangements of the components to form said composite article, each candidate process implementing a different, limited strategy for defining a number of candidate arrangements and evaluating said candidate arrangements in terms of predetermined parameters to find a best candidate arrangement among them; and
- comparing the best candidate arrangements generated by the different candidate
15 processes to identify among them an overall optimal arrangement; and
- outputting a record of the best candidate arrangement, for use in the manufacture of said composite article.
2. A method as claimed in claim 1 wherein there is an initial data preparation step
20 where the set of components that will make up the composite article is divided into subsets, each subset of articles having a certain dimension in common, whereby a list of dimensions and a list of the number of components that have each of these dimensions are generated from the user's input.
- 25
3. A method as claimed in claim 1 or 2 wherein at least one of said candidate processes attempts arrangements having central assemblies of different numbers of components.
- 30
4. A method as claimed in claim 1, 2 or 3 wherein the received component dimensions are stored in lists such that components of the same dimensions are grouped together and processed in blocks.

5. A method as claimed in claim 4 wherein in at least one of said candidate processes permutations of the blocks of components are calculated and used to represent the possible arrangements.
- 5 6. A method as claimed in any preceding claim wherein at least one candidate process implements a strategy to define a central assembly containing at least one of the components, and to arrange the remaining components around said central assembly.
- 7 A method as claimed in claim 6 wherein at least one of the candidate processes is
10 performed by building a central assembly from at least one component and by placing the remaining components in at least one substantially symmetrical concentric layer around said central assembly.
8. A method as claimed in claim 6 or 7 wherein at least one of the candidate
15 processes attempts building up a central assembly incrementally using material additional to the defined said components, thus increasing the number of components that can be accommodated in a surrounding layer.
9. A method as claimed in claim 8 wherein the central assembly is built up in steps
20 of 2-5% diameter up to a predefined maximum.
10. A method as claimed in any of claims 1 to 5 wherein at least one of the candidate processes attempts placing one or more components of suitable dimensions in the interstitial spaces of a central assembly made up of a plurality of other components.
25
11. A method as claimed in claim 10 wherein central assemblies consisting of a limited number of components the largest overall diameter of any component are considered, the candidate process attempting to place one or more further component articles of suitable dimensions in the interstitial spaces of the central assembly.
30
12. A method as claimed in any preceding claim wherein at least one of the candidate processes attempts grouping together smaller component articles thus creating sub-

assemblies of component articles which have similar dimensions to those of larger component articles within the set of components.

13. A method as claimed in any preceding claim wherein there is provided an
5 additional step identifying different component types within a subset of components having the same external dimensions, said component types being differentiated only at some stages in the process.

14. A method as claimed in any preceding claim wherein at least one of said candidate
10 processes considers symmetry as a property of a candidate arrangement, and includes in the arrangement one or more components in addition to those specified by the user, the size, number and position of said additional component(s) being determined by said candidate process to provide a more symmetrical arrangement.

15 15. A method as claimed any preceding claim wherein at least one of said candidate processes considers symmetry as a property of a candidate arrangement, and adds layers of additional material to build up the diameter of one or more of said components to match more closely the diameter of another larger component, to provide a more symmetrical arrangement.

20

16. A method as claimed in any preceding claim wherein in said comparing step the optimal arrangement of the composite article is taken to be that which has the smallest diameter.

25 17. A method claimed in claim 16 wherein if the smallest two arrangements have the same diameter and at least one of them includes filler components additional to those specified by the user, then the optimal arrangement of the composite article is taken to be that with the least number of fillers.

30 18. A method as claimed in any preceding claim wherein the resultant optimal arrangement is recorded in a form compatible with a generic computer-aided design package.

19. A method as claimed in any preceding claim wherein the weight of the product is also calculated and output as part of said record.

20. A method as claimed in any preceding claim wherein further mechanical
5 properties of the designed product are calculated and output as part of said record.

1/12

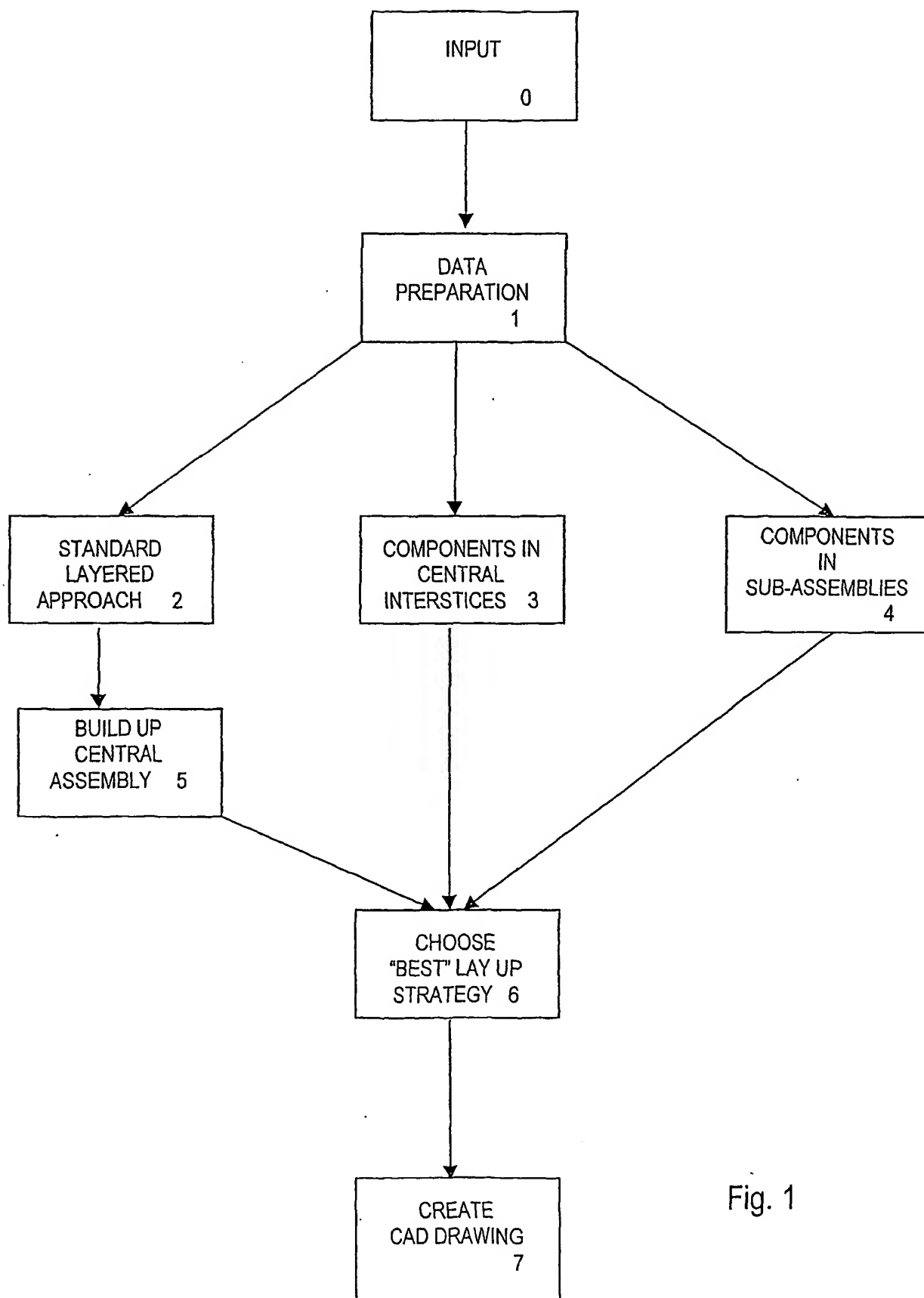


Fig. 1

2/12

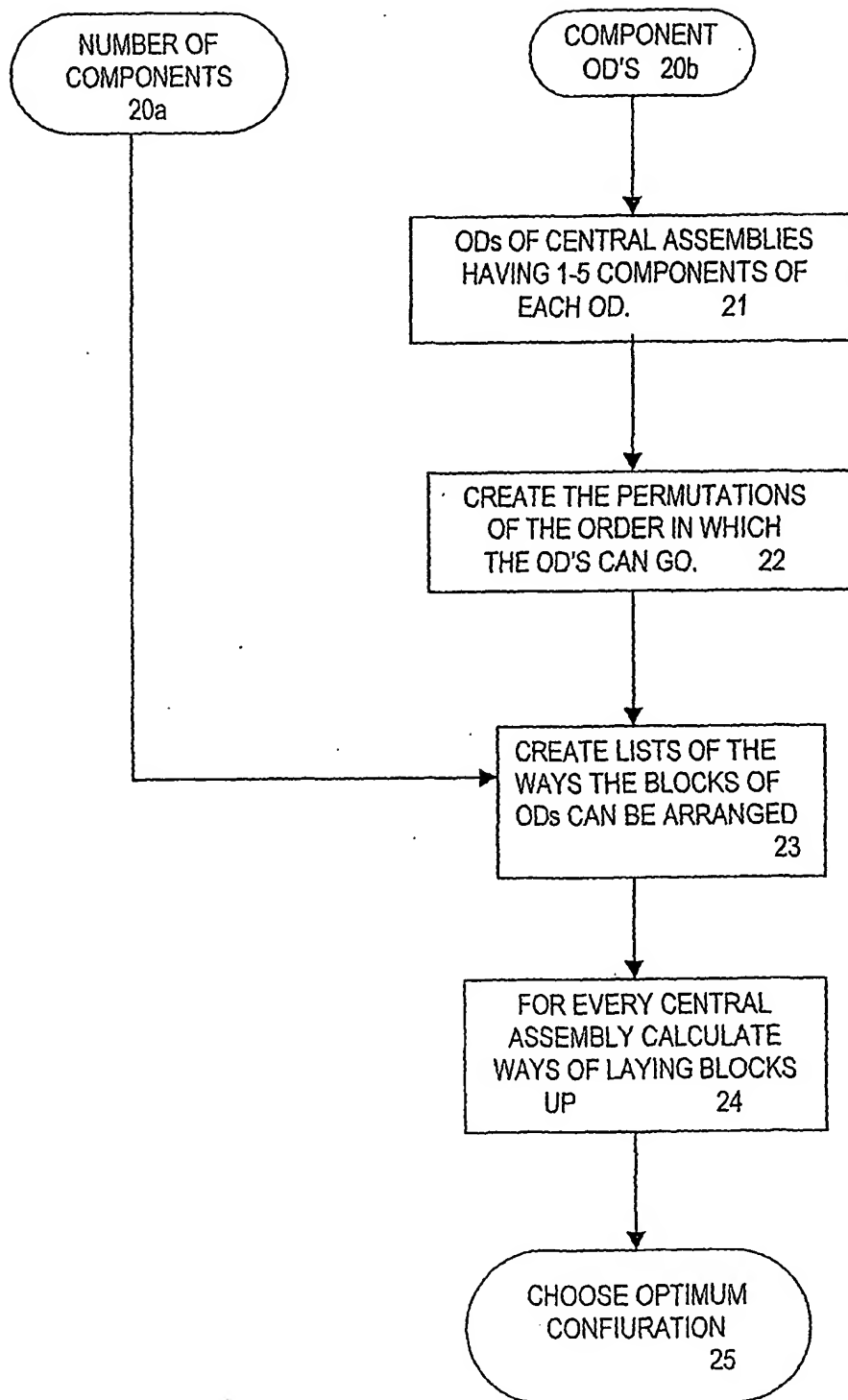
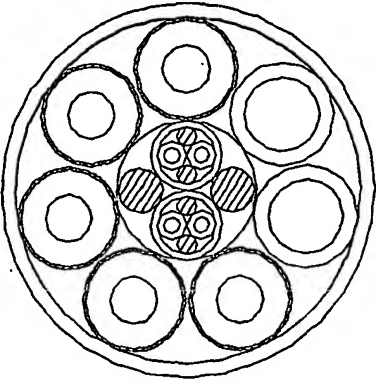


Fig. 2

3/12

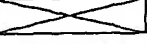
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Dr'g No:		Date:		
		Rev:		



Finished Diameter: 71.000mm

Mechanical Properties:

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	static	dynamic	air	seawater
calculated	recommended min.		calculated	

Drawn By:		Approved By:		Scale:	N.T.S.
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INPUT:

2 HOSE @ 19.6MM
 5 HOSE @ 18.5MM
 2 PAIR @ 13.2MM

Fig. 3

4/12

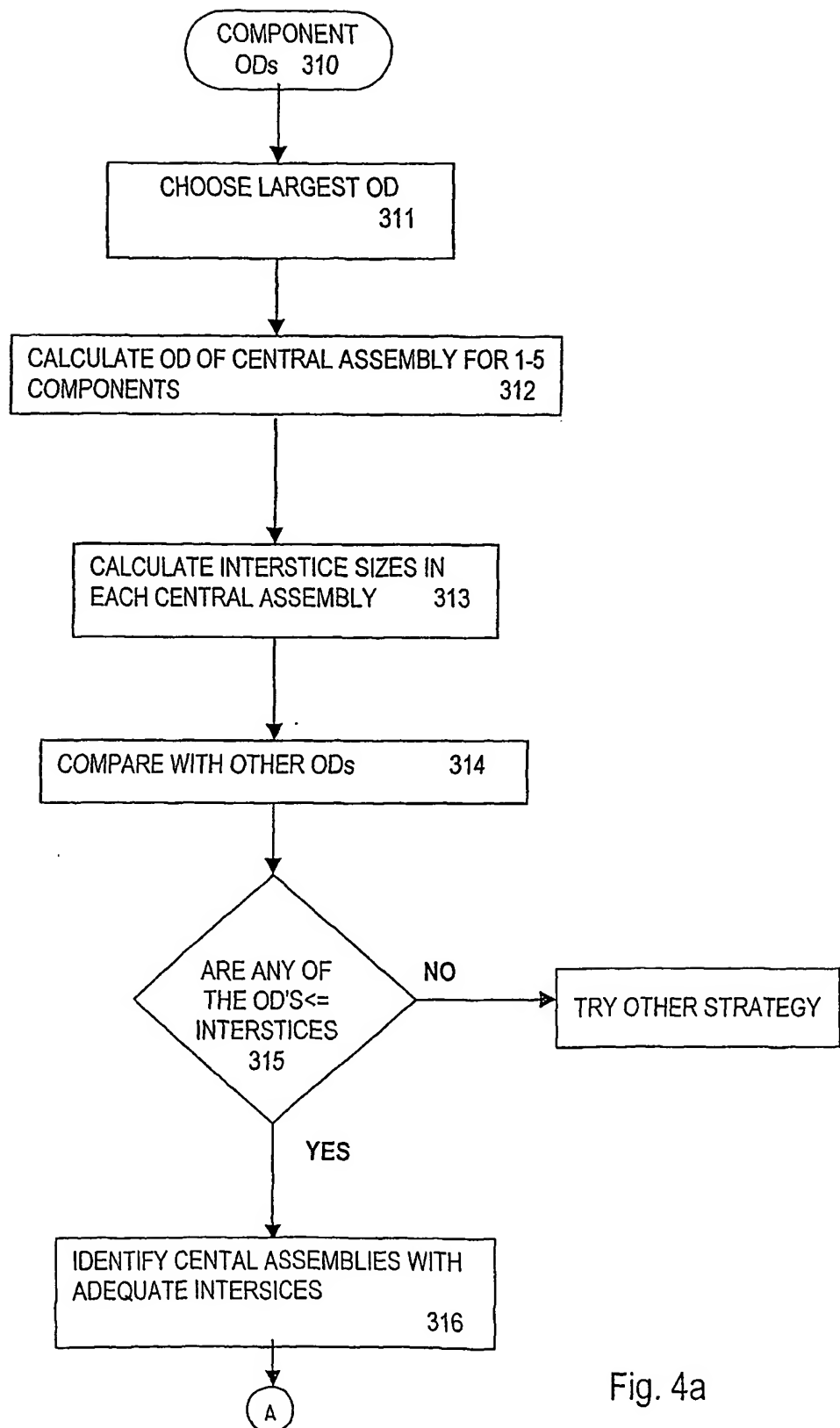


Fig. 4a

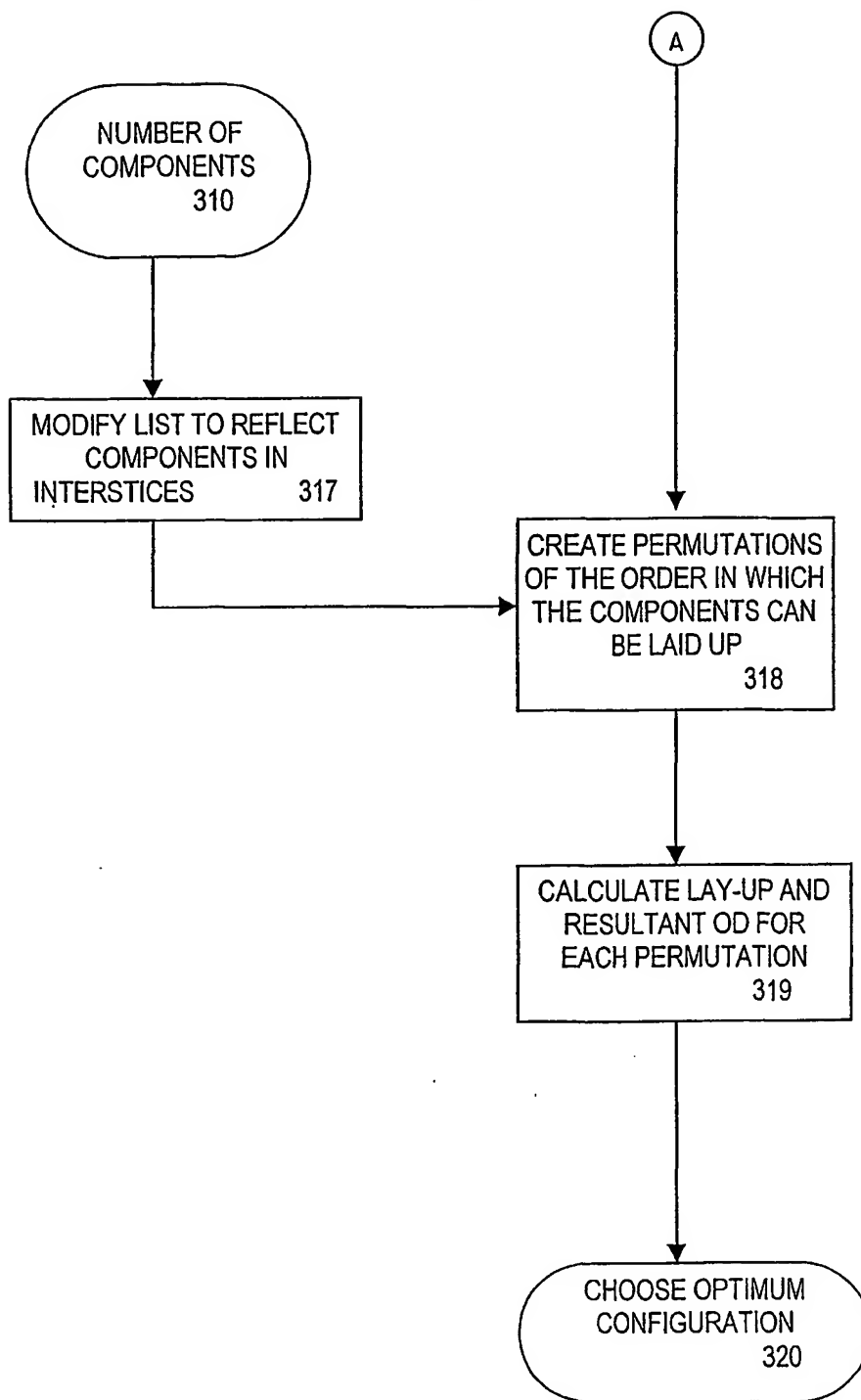
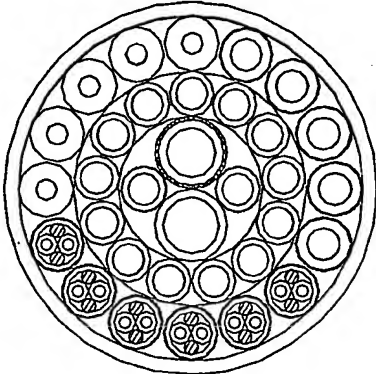
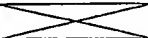


Fig. 4b

Title:																																						
Dr'g No:		Date:																																				
		Rev:																																				
																																						
<p>Finished Diameter: 105.000mm</p> <p>Mechanical Properties:</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th rowspan="2">Breaking Load</th> <th colspan="2">Bending Radius</th> <th colspan="2">Weight</th> </tr> <tr> <th>static</th> <th>dynamic</th> <th>air</th> <th>seawater</th> </tr> </thead> <tbody> <tr> <td>calculated</td> <td>recommended min.</td> <td></td> <td>calculated</td> <td></td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> </tbody> </table>					Breaking Load	Bending Radius		Weight		static	dynamic	air	seawater	calculated	recommended min.		calculated																					
Breaking Load	Bending Radius		Weight																																			
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Drawn By:		Approved By:		Scale: N.T.S.																																		

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INPUT:

1 HOSE @ 18.5MM
 15 HOSE @ 12.5MM
 5 HOSE @ 15.5MM
 5 HOSE @ 14.7MM
 1 HOSE @ 20.5MM
 6 PAIRS @ 14.7MM

Fig. 5

7/12

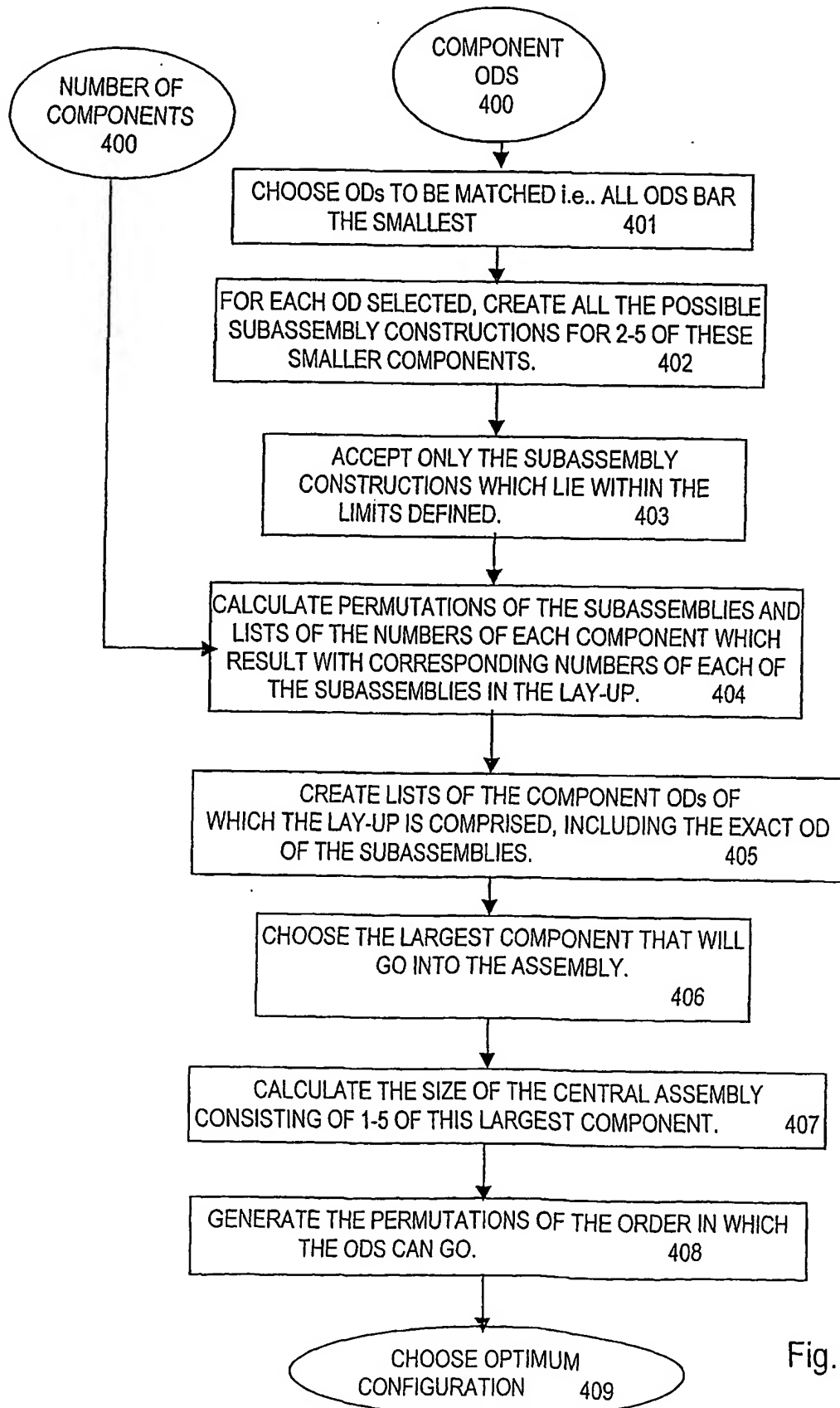
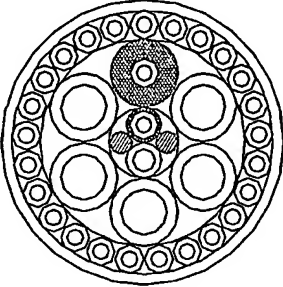


Fig. 6

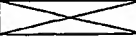
Title:			
Dr'g No:		Date:	
		Rev:	



Finished Diameter: 125.496 mm

Mechanical Properties:

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calculated	recommended	minimum	calculated
	static	dynamic	
	mm	mm	
	613.724	1223.586	

Drawn By:		Approved By:		Scale:	N.T.S.
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INPUT:

5 HOSE @ 30MM
1 HOSE @ 15.5MM
27 HOSE @ 12.5MM

Fig. 7

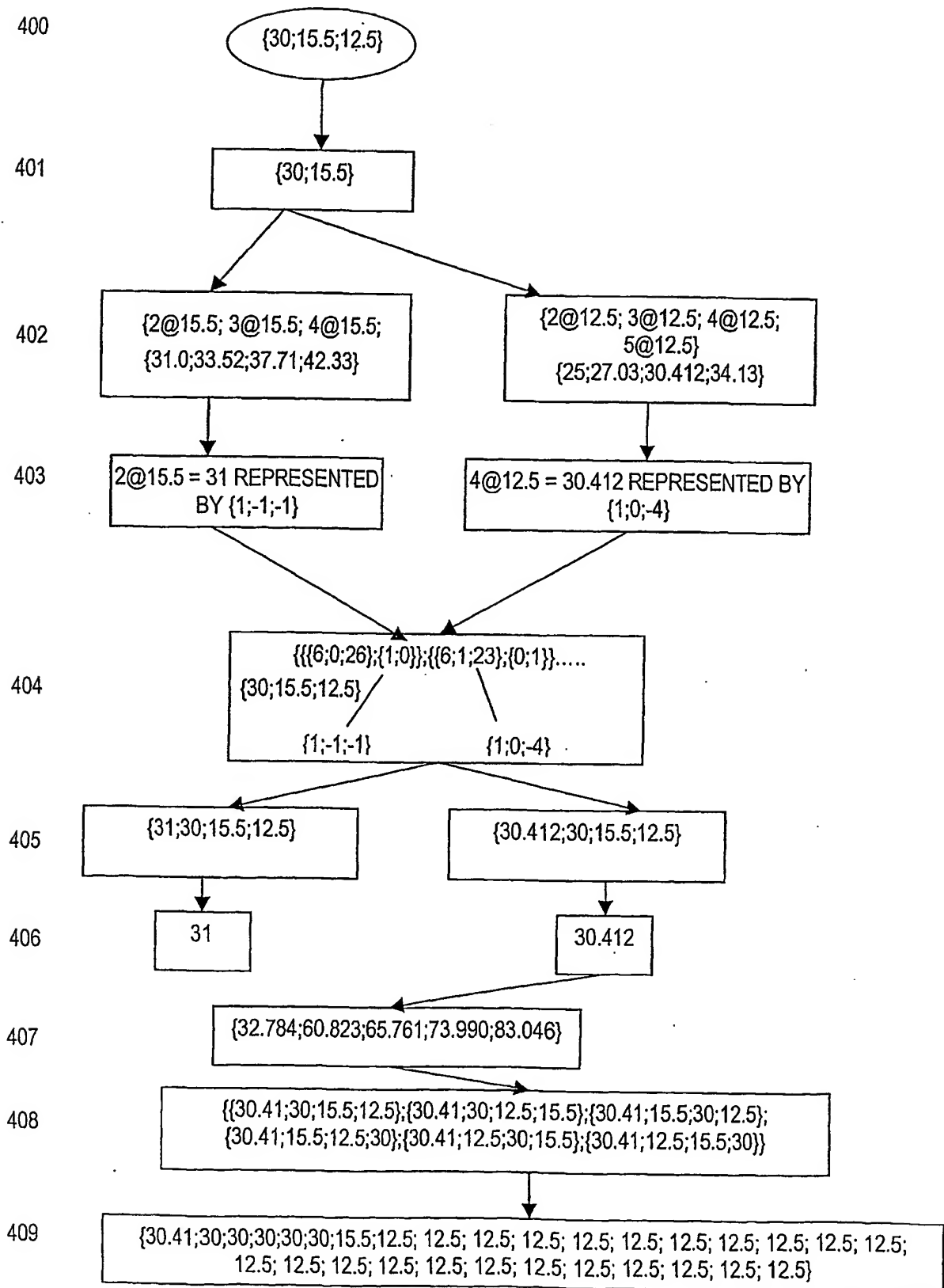


Fig. 8

10/12

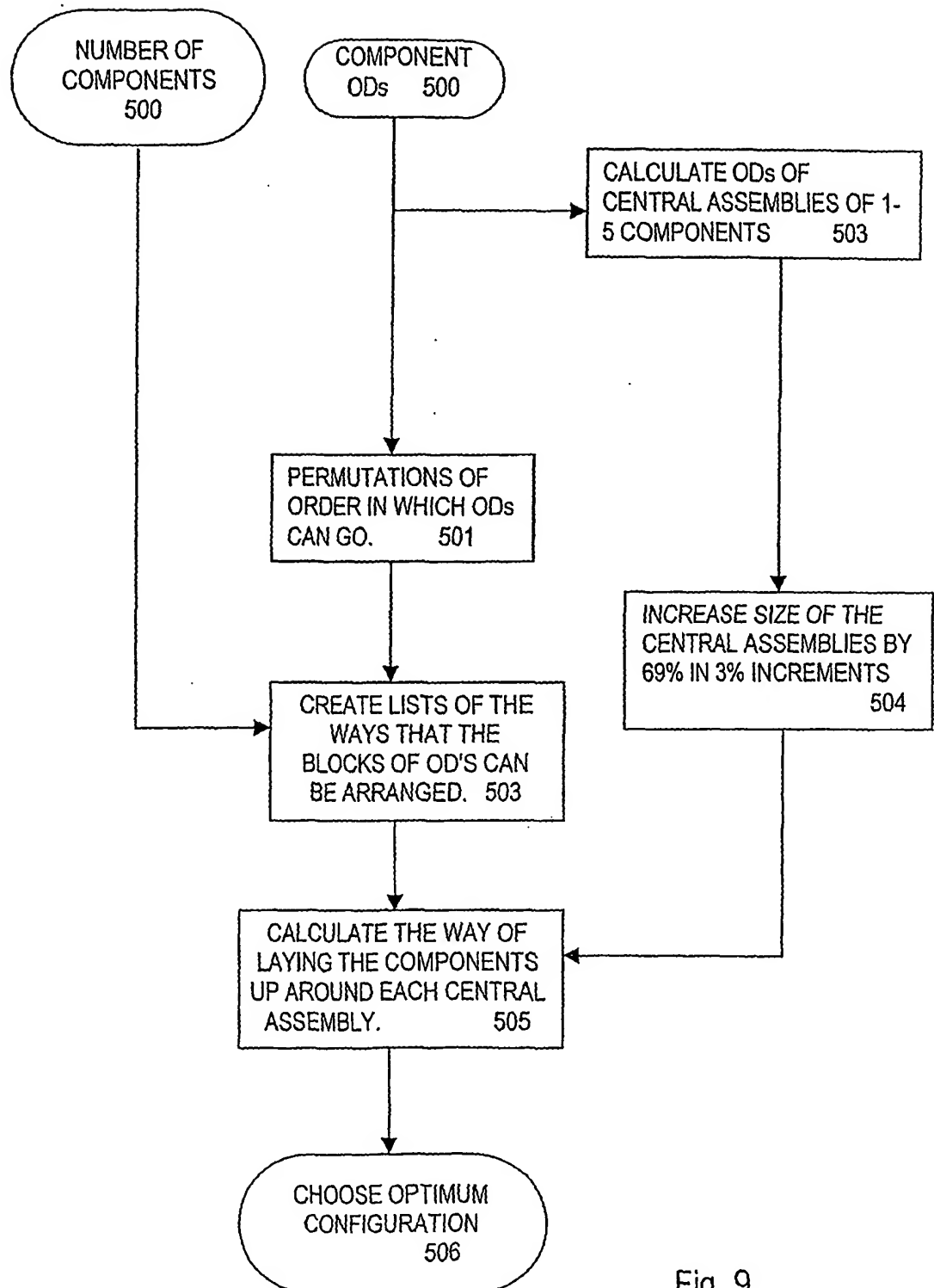
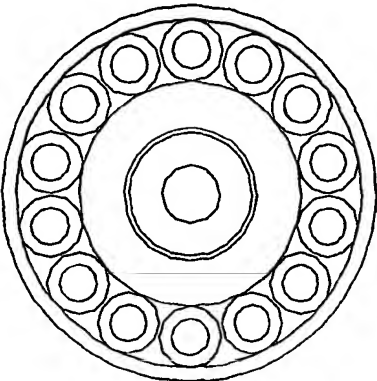


Fig. 9

11/12

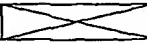
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Dr'g No:		Date:	
		Rev:	



Finished Diameter: 91.000mm

Mechanical Properties:

Breaking Load	Bending Radius		Weight	
calculated	recommended min.		calculated	
	static	dynamic	air	seawater

Drawn By:		Approved By:		Scale:	N.T.S.
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INPUT:

1 HOSE @ 30MM
14 HOSE @ 15MM

Fig. 10

12/12

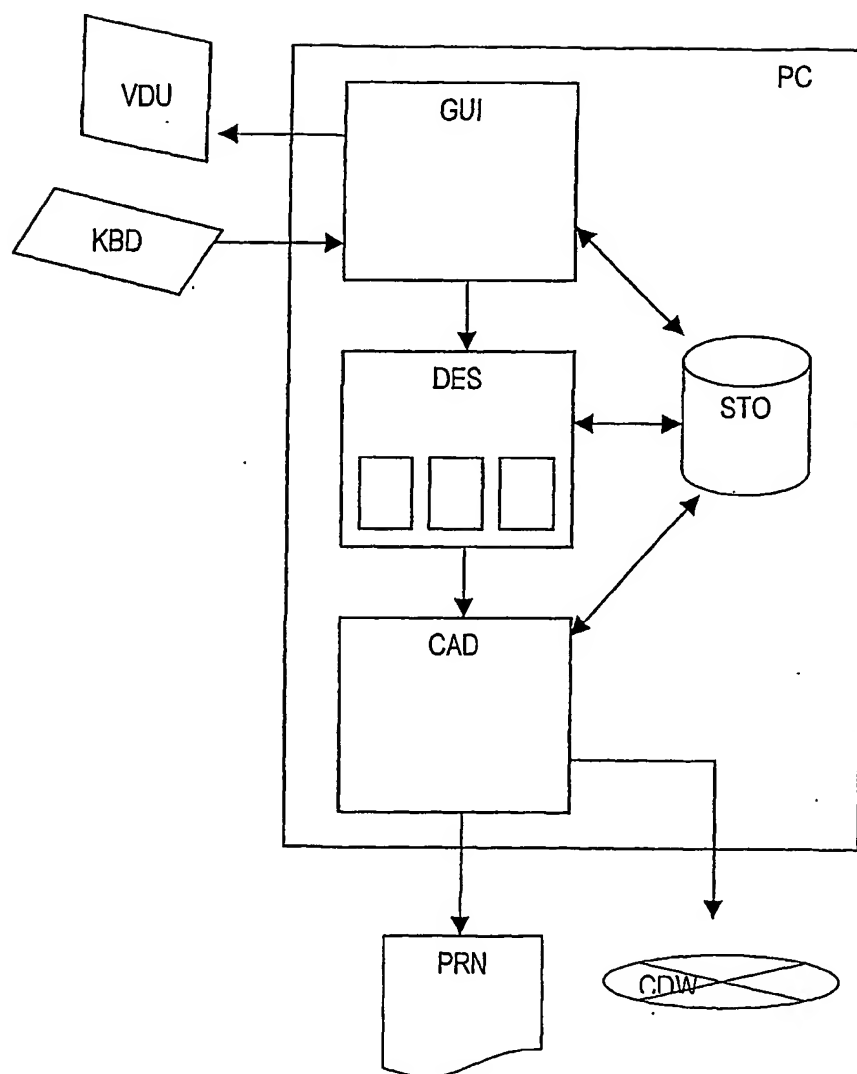


Fig. 11